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WATERSHED MANAGEMENT IN THE ROCKY MOUNTAIN ALPINE AND SUBALPINE ZONES

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In the semiarid portions of the Western United States, water has been an important--if not the controlling--factor in the economy since the first permanent settlement. Water diversion and reservoir systems were among the first engineering improvements in many western communities, and are still an important function of many local and Federal agencies. Such diversion and storage operations are based on the idea of gathering and storing the water during the annual peak flow and the occasional heavy snow year so it can be released when needed. In spite of the success of this system, there is still need for land-management practices that can increase total annual water yields or improve summer streamflow.

Very early work was done at Wagon Wheel Gap, Colorado (Bates and Henry 1928).[2] About 20 years ago watershed management research was started in the high-elevation coniferous forests of Colorado. These studies were concentrated in the headwaters of the Fraser River where about three-fourths of the precipitation falls as snow and is held in the snowpack until late spring or early summer when it is released as snowmelt. Forests in this area are composed of lodgepole pine (Pinus contorta Dougl.), Engelmann spruce (Picea engelmannii Parry), and subalpine fir (Abies lasiocarpa (Hook.) Nutt.). The high ridges and summits are covered by alpine tundra vegetation or rock.

In the early 1940's studies were carried out to determine: (1) the relationship between vegetative types and the water equivalent of the snowpack, and (2) the influence of the size of forest openings on the water equivalent of the pack under natural stands of trees. The snowpack was found to be least under the dense pine forests, 14 percent greater in the grasslands, and 30 percent greater in the stands of deciduous aspen (Love and Goodell 1960). The study of forest openings was carried out in mature lodgepole pine where trees averaged 80 feet tall and openings as large as 60 feet in diameter could be found. Under such conditions the water equivalent of the pack was least in the dense forest and greatest in the center of the largest opening. There was a linear increase in water content from the edge of the forest toward the center of the openings (Wilm and Dunford 1948).

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[2]Names and dates in parentheses refer to Literature Cited, page 6.

The next series of studies was to determine the effect of forest management practices on the snowpack. Three variables were evaluated: Intensity of cut was studied in a mature lodgepole pine forest, pattern or type of cut in mature spruce-fir, and intensity of thinning in young lodgepole pine. The basic findings from these plot studies were:

1. For 5-acre plots surrounded by mature forests, the water equivalent of the snowpack increased with the intensity of cutting. This was also true for a thinning operation on smaller plots in a young forest. In mature lodgepole pine, clear cutting increased the water equivalent of the snowpack by 31 percent; however, the snow disappeared in both the cut and the uncut areas at about the same time. This indicates a faster melt rate in the open areas than in those shaded by trees (Wilm and Dunford 1948).

2. The pattern of timber cutting on small plots within a forest does not affect the water equivalent of the snowpack so long as each pattern removes the same proportion of the original stand. When 60 percent of the mature spruce-fir forest was removed by any of three different cutting patterns--single-tree selection, group selection, and strip clear cut--the increase in snowpack was the same for all patterns. In other words, the snowpack responded to the number of trees cut but not the pattern or arrangement of the cut. Melt rate was found to be slower in the group-selection cuts since the snow was better shaded here than in the other cut areas.

These early plot studies were interpreted to mean that interception was an important phenomenon where timber in snowy regions is managed for increased water yields. The snow held in the crowns of the coniferous trees often melted and the melt water evaporated from the twigs and needles, or at lower temperatures the snow sublimated into the atmosphere directly. In either case, the water held as snow on the trees never became part of the snowpack and was lost to streamflow. Although these plot studies showed rather conclusively that there was more snow in forest openings than under dense forests, the plots were too small to allow us to be sure that the increase of snow in the openings was due just to reduced interception in these areas. Perhaps there was more snow in the openings because extra snow blew into them from the crowns of the surrounding trees, or because the surrounding forest acted as a windbreak that caused wind-transported snow to settle into the openings. These and other uncertainties made it very hard to use the findings from the early plot studies to predict what the net effects on streamflow would be if an entire watershed were treated.

Therefore, the next step in this sequence of research was to treat an entire watershed and to measure the change in the streamflow brought about by the treatment. A 714-acre watershed in the upper Colorado River basin, called Fool Creek, was selected for treatment. This watershed had a northern exposure, was 2 miles long, and extended from an elevation of 9,600 to 11,500 feet. Mature to overmature forests covered 550 of the total 714 acres. This 250- to 300-year-old stand was 55 percent lodgepole pine--mostly on lower slopes and upper ridges--and 45 percent spruce-fir in the moist, protected places at higher elevations. The remaining 164 acres had been burned almost 100 years ago and supported submerchantable spruce and fir (fig. 1).

After this watershed was calibrated so its streamflow could be predicted from the flow of an adjacent stream, one-half of the mature timber on 550 acres was clear cut in alternate strips of cut and uncut timber (278 acres clear cut--35 acres for roads, 243 acres in mature timber). The strips were of variable widths. Thirteen miles of roads were put in prior to the logging operation. There was no cutting in the submerchantable timber in the upper part of the watershed, nor in the strip 90 feet on either side of the main stream channel (Goodell 1958).

The change in streamflow from Fool Creek for the first 5 years following treatment (U.S. Forest Serv. 1962) was as follows:

Figure 1.--Fool Creek watershed (center) has been treated to improve water yields. The untreated watershed (right) is the control. Fraser Experimental Forest, Fraser, Colorado. June 25, 1964.

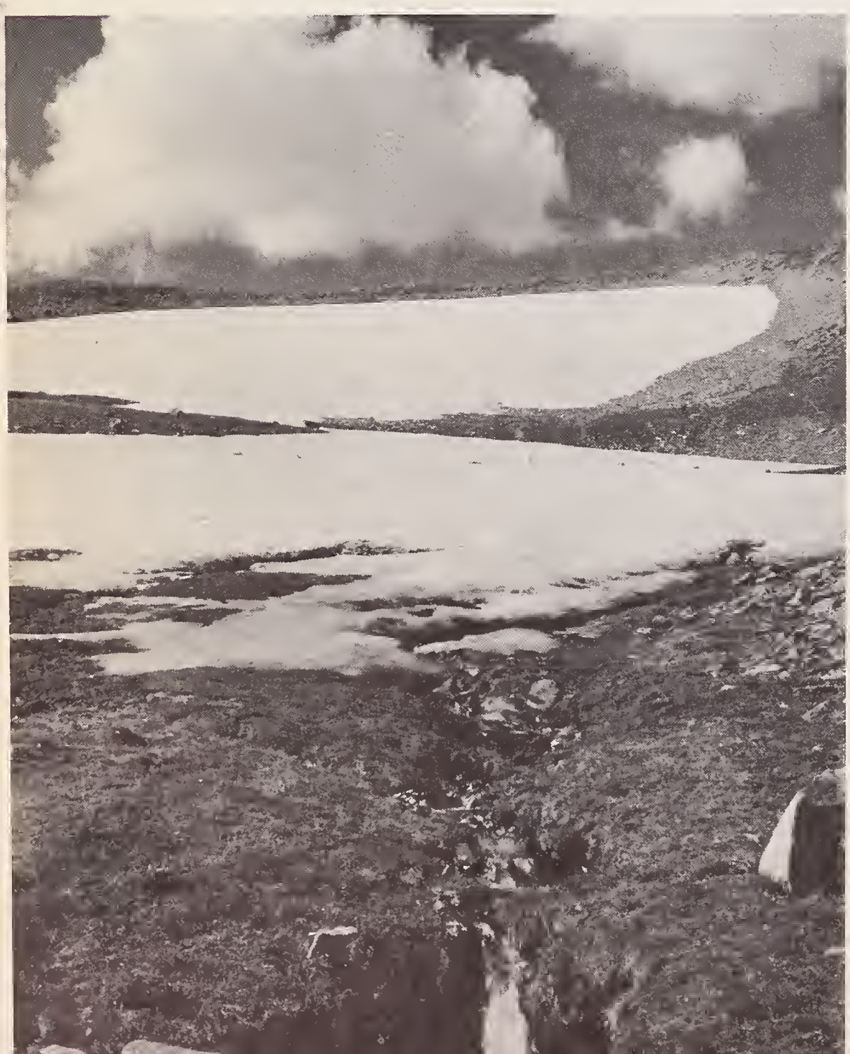
	Yield in area inches		
	Predicted[3]	Actual	Increase
1957	19.6	23.0	3.4
1958	11.4	13.5	2.1
1959	10.5	13.6	3.1
1960	11.1	14.9	3.8
1961	8.8	10.9	2.1

[3]*Yield that might have resulted, according to calibration data, if the area had not been treated.*

Removing the timber from 39 percent of this watershed increased the water yield by 23.5 percent. Most of the increase was due to an enlarged spring runoff. Snowmelt started earlier and produced a higher peak on the cut watershed. There was very little increase in streamflow during the late summer or early fall months. In spite of the increase in runoff, the instantaneous flow from Fool Creek has been less than 22 cubic feet per second per square mile (c.s.m.) and the sediment load has been less than 1.5 cubic feet (wet volume) per acre per year (U. S. Forest Serv. 1961).

Earlier evidence of the change in streamflow following the removal of timber was furnished by the disastrous beetle outbreak in the spruce forests of western Colorado in the early 1940's. A regression analysis was made to compare the streamflow from one area on the White River drainage where 60 percent of the trees had been killed by beetles with that from a nearby area where there had been no beetle damage (Love 1955). Eight years of record showed a 25 percent increase in streamflow from the area where trees had been beetle-killed. Again the increase was the result of higher peak flows during the spring snowmelt (U. S. Forest Serv. 1961).

In both the Fool Creek and the White River studies, the increase in streamflow was the result of happenings on only part of the watershed: on Fool Creek, timber was cut on only 40 percent of the area; on the White River, insects killed the trees on 60 percent of the watershed. If the increases in streamflow that followed these events are attributed to the "treated" areas alone, they are about twice as large as would be expected from the early plot studies on interception. Hence, the watershed data indicate that the increase in streamflow after the harvesting or killing of trees is due as much to the reduction of evapotranspiration as it is to the reduction in interception.



Current watershed studies in the spruce-fir zone are concentrated on learning more about the different kinds of evapotranspiration losses. To determine whether coniferous trees transpire during the winter, and if so where and when such losses take place, an instrument has been developed that will detect the movement of sap in a tree (Swanson 1962). In its present state of development, this instrument also gives a comparative measure or an index to the amount of sap movement taking place. Such information will help determine the seasonal course of transpiration in coniferous trees. Measurements are made on individual trees so the influence of site factors as well as size and species of trees can be studied.

The discussion to this point can be summarized by saying research in watershed management in the subalpine zone is concerned with the effect of vegetation on water yield. In contrast, watershed management in the alpine zone is concerned primarily with the aerodynamics of the wind transport and deposition of snow. Its goal is to increase late summer streamflow--improve the timing.

The decision to study the possibility for increased summer streamflow from alpine areas was based on two observations: that snowfields yield much melt water during the summer, and that summer streamflow is higher for streams draining areas where large amounts of snow persist until late summer than it is for adjacent streams with few summer snowbanks (fig. 2,3).

The amount of water released by snowfields during summer months was studied in the Colorado mountains during the summers

Figure 2.--A typical alpine snowfield in the Front Range of Colorado during the summer. Most years, at the beginning of the summer, snow completely fills the upper bowl and extends below camera point; very little, if any, snow is left by mid-September. Niwot Ridge, Colorado. August 24, 1957.

Figure 3.--Water yield from alpine snowfields was estimated from ablation and water equivalent of the snow. Ablation was measured on stakes; water equivalent was measured with a snow sampler. Precipitation, temperature, and humidity were recorded adjacent to the snowfields. Rollins Pass, Colorado. August 22, 1955.

of 1955 through 1958. Four sites along the eastern side of the Front Range in central Colorado were visited weekly. Ablation and snow density were measured and weather factors were recorded. Average ablation of snow was found to be 1.9 feet per week during July and August for the first 2 years and slightly higher the next 2 summers (Martinelli 1959). Density increased during the summers but averaged between 0.55 and 0.65 gm/cm³.

Short-term studies of the moisture exchange between the snow surface and the atmosphere showed both condensation and evaporation at the snow surface. A diurnal pattern of moisture exchange was found with condensation at nights, evaporation in mornings, and either evaporation or condensation in the afternoons, depending on weather conditions. The net exchange during one 2-week period in August 1957 was a gain of moisture at the snow surface from condensation. During an 11-day period in July 1958, however, there was a net loss of moisture from the snow due to evaporation. In all cases the moisture exchange between the snow and the air averaged 2 to 3 percent of the daily melt and never exceeded 4.5 percent of the daily melt (Martinelli 1960).

By combining the above data, we see that on the average 22.5 inches of snow disappear from alpine snowfields each week in July and August. This snow has a density of about 0.60, and even with dry, windy conditions only 2 percent of the water equivalent released by ablation is lost through evaporation. Hence, the summer snowfields yield about 13.2 inches of water ($22.5 \times 0.6 \times 0.98 = 13.2$) per week per unit area during July and August.

To this point the alpine snow studies had been concerned with data from individual snowfields. To see just how extensive such snowfields were and to get an idea of their potential contribution to streamflow, aerial photographs were taken of a selected portion of the Front Range in central Colorado twice during the summer of 1956. In an area of 277,000 acres (above 6,000 feet), 8,000 acres of alpine snow disappeared between June 23 and September 16. This snow produced a potential streamflow of 41,300 acre-feet of water; 32,000 acre-feet of this was produced in July and August.[4]

The term potential streamflow is used because no measure was made of evaporation losses from the wet soil surrounding the

[4] Martinelli, M. Jr. An estimate of runoff from alpine snow fields during the summer of 1956. 1965. (In preparation for publication, Rocky Mountain Forest and Range Expt. Sta., U. S. Forest Serv., Ft. Collins, Colo.)

snowfields nor from the water surfaces between the snowfields and the gaging stations. Nor were data available on the ground-water recharge and storage. Streamflow measurements were available for only three small drainages within the larger study area. When just these three streams are considered, the water-yield potential from alpine snowfields amounted to between 60 and 95 percent of the total measured streamflow during July and August 1956.

Once it had been established that summer snowbanks were an important source of summer streamflow, the next step was to try to develop management techniques to capitalize on these finds. Winter observations had indicated that the deep snowbanks formed in the lee of terrain features, small clumps of vegetation, or anything else that provided protection from the wind. These observations also showed that the depth of snow was controlled, at least to a certain extent, by the upwind edge of the terrain feature, and further that many of the natural catchments tended to fill with snow relatively early in the winter.

Tests were started in 1958-59 to see if common slat-and-wire snow fencing placed at the upwind edge of the natural catchments would increase the depth of snow trapped in these areas. There are now 4 years of record from 5 areas and 3 years of record from another[5] (fig. 4).

At three of the test sites, the fences made an appreciable increase in snow depth. At two of the sites the increase in snow depth due to the fence was not significant; at another site two different patterns of fence have failed to improve the natural catch. Best results so far have been when fences were located on the crest of the main ridge, with windswept tundra to the windward and a steep natural catchment immediately to the leeward. Good results were also obtained at places in the lee of the main ridge where the terrain was relatively level upwind of natural depressions 20 to 30 feet deep. Poorest results came from an area where the windward approach was down a rather steep slope. In this case, the catchment was 50 to 60 feet deep and rather large. At this spot none of the artificial barriers tried so far have given accumulation patterns as favorable as the natural pattern.

Weather data for the past several winters have shown that a relatively few storms account for most of the snow that accumulates under both natural and fenced conditions. Between 50 and 65 percent of the annual accumulation took place in the five biggest storm periods, and between 25 and 40 percent during the two biggest storm periods each year for the past 4 years. These periods of heavy accumulation are thought to be during or immediately after storms; however, more field data are needed for confirmation.

Additional watershed management research in the alpine area is being undertaken to determine the synoptic situation that produces maximum deposition in the catchments. These studies will also provide detailed information on the wind structure and the concentration of blowing snow in the lower layers of the air during periods of heavy snow drifting. Such information should be of help in the design of more effective snow fences and in the selection of optimum sites of such barriers.

[5]*Martinelli, M. Jr. Accumulations of snow in alpine areas, and means of influencing it. 1965. (In preparation for publication, Rocky Mountain Forest and Range Expt. Sta., U. S. Forest Serv., Ft. Collins, Colo.)*

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Figure 4.--Slat and wire snow fencing effectively increase snow depths when properly located. Most effective sites are along ridge crests just to the windward of deep natural snowfields. Straight Creek Pass, Colorado. February 24, 1963.

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